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Measuring Human Exposure to Carbon Monoxide in Washington, DC, and Denver, Colorado during the Winter of 1982-1983

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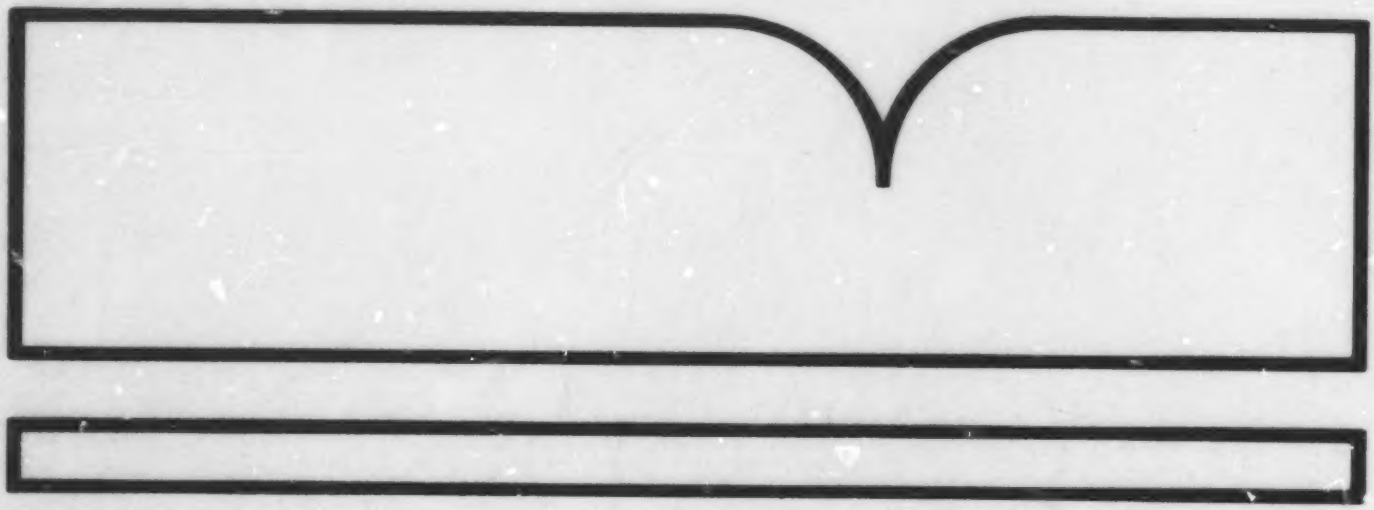

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16. ABSTRACT

In the past, no scientifically valid approach for determining the exposures of an urban population to a pollutant was available. Recently, EPA successfully field tested two separate but complementary approaches for determining population exposures to air pollution: (a) direct measurement of exposure profiles of a representative random sample of the population with personal exposure monitors, and (b) an indirect approach which combines human activity pattern data with microenvironmental concentration data to estimate exposure profiles. In the winter of 1982-83, the two approaches were field tested. This effort provides a rich human exposure data base and a methodology that can be applied to other pollutants and other urban areas.

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Measuring Human Exposure to Carbon Monoxide in Washington, D.C., and Denver, Colorado, during the Winter of 1982–1983

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■ A methodology for measuring the frequency distribution of carbon monoxide (CO) exposure in a representative sample of an urban population has been developed and applied in two urban areas: Washington, DC, and Denver, CO, during the winter of 1982–1983. Exposure data using personal exposure monitors (PEMs) were collected, together with activity data from a stratified probability sample of residents living in each of the two urban areas. Well established survey sampling procedures were used for the selection of individuals. The resulting exposure data permit estimates of CO exposure for the eligible populations of the two areas, as well as statistical comparisons between population subgroups (e.g., commuters vs. noncommuters and residents with and without gas stoves). Results indicated that over 10% of the residents in Denver and 4% of the Washington, DC, residents were exposed to CO levels above 9 ppm for 8 h during the study period. The data also provide evidence for judging the accuracy of exposure estimates calculated from fixed site monitoring data.

Introduction

The concept of directly measuring personal exposure to a pollutant is not new. For example, occupational exposures to radiation and carbon monoxide (CO) have been measured for years by using personal exposure monitors (PEMs). However, PEMs that measure concentrations expected to be an order of magnitude lower than those found in occupational settings have not previously been available for use by the general public. With the rapid advance of technology in the past decade, instrument manufacturers have been able to miniaturize both circuitry and mechanical components, making it possible to directly measure personal exposure (*1*). A recent article summarizes a number of studies that have made use of these new instruments (*2*).

The need for population exposure data has grown with the need to improve risk assessment methodology of which exposure assessment is an integral part. Until this study, the U.S. Environmental Protection Agency did not have population estimates derived from personal CO exposure measurements which were statistically designed to be representative of a particular urban area.

A study plan was formulated that would develop and field test a methodology appropriate for measuring CO exposure on an urban scale that was broad enough to accommodate other pollutants of concern. Study designs applicable to Denver, CO, and Washington, DC, were developed by the Research Triangle Institute (*3*). The study was carried out in Washington, DC, under contract to Research Triangle Institute (*4*) and in Denver, CO, under contract to PEDCo Environmental (*5*). Sampling was performed between Nov 1, 1982 and Feb 28, 1983, the period of the year when maximum fixed-site CO levels usually occur.

Methodology

The study design was patterned after studies routinely conducted by social scientists and provides a mechanism for making statistically valid inferences from a probability sample to a well-defined target population. One example of a national study that uses such survey sampling techniques is the National Health and Nutritional Examination Survey, a major quadrennial study conducted by the National Center for Health Statistics.

The sample for the CO exposure study was chosen in such a manner that it included a disproportionately large representation of certain subpopulations of special interest such as commuters, residents of homes with unvented gas stoves, etc. Weights reflecting the sampling procedure were applied to the collected data to obtain unbiased estimates of the frequency distributions for exposures in the overall population and in the particular subpopulations of interest. Answers to the following seven questions determined the basic framework for the study.

(1) What is the geographic area of interest? We chose to study the metropolitan areas of Washington, DC, and Denver, CO. These areas provide variations in elevation, in land area, in population density, in commuter patterns, in weather, and in activity patterns. The Washington Metropolitan Area was precisely defined to be all areas simultaneously inside the Washington Standard Metropolitan Statistical Area (SMSA) and inside the Washington Urbanized Area as defined by the 1980 Decennial Census. The Denver Metropolitan Area was defined to include the

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areas within the incorporated cities of Denver, Englewood, Arvada, Aurora, and Commerce City.

(2) What is the target population? We chose to study noninstitutionalized, nonsmoking residents aged 18–70 living in the geographical areas of interest. For inference purposes, the number of target population members residing in the two areas is estimated to be approximately 1.22 million and 245 000 for Washington and Denver, respectively.

(3) What variables may influence an individual's exposure? In general, the answer to this question depends upon the pollutant sources. Our study focused on CO emissions that originate primarily from mobile sources. Indoor exposures may also be affected by unvented combustion sources (gas stoves and kerosene heaters), intrusion of CO from garages, and the presence of smokers. Information about the distribution of these variables within the population allowed identification of broad subgroups from which individuals were selected. Subgroups containing individuals likely to be exposed to the highest levels of CO from major expected sources indoors, outdoors, and in transit were oversampled.

(4) How should the sample be chosen? Every eligible population member has a nonzero probability of being selected into the sample. Our procedure was to use a stratified, three-stage, probability-based sampling procedure in each city (*6*). During the first stage the geographic area was divided according to Bureau of Census standardized areas, and a sample of these areas was selected. Address and telephone number listings compiled by Donnelley Marketing Corp. (from telephone directory listings and vehicle registration records) were used as the sampling frame for selecting households during the second stage. A knowledgeable household member was given a short screening interview to obtain information about each household member. The household screening data were used in the third stage to enable oversampling of eligible individuals (i.e., nonsmoking, aged 18–70) with characteristics believed to be positively correlated with CO exposure. The individuals in the third stage sample were asked to carry a personal CO monitor and fill out an activity diary. A detailed discussion of the sample design is available (*3*).

(5) How many individuals should be chosen? The number of individuals that should be selected is a function of the size of the subgroups of the population one wishes to study and the expected response rate of the study. We selected individuals from 12 primary strata based upon three screening variables: commuting (long and short), gas appliances (space heater, gas stove, other), and attached garage (yes, no). Our study goal was to sample for a duration of approximately 100 days, with approximately 10 individuals monitored per day. In other words, our goal was to achieve approximately 1000 person-days in each city.

(6) How many days should an individual carry a monitor? A pilot study of CO exposures was conducted in Los Angeles, CA, in 1980 (*7*). Results from this study of 10 individuals indicated that we could expect more variation in CO exposures from subject to subject than variation within a subject across days. For example, the standard deviation on the average 24-h CO level for the first day of the pilot study across the 10 individuals was 3.5 ppm, which was slightly higher than the maximum individual standard deviation over all the sampling days of 3.3 ppm. Furthermore, since monitoring costs are approximately the same for multiple sampling of the same individual in comparison to costs for monitoring different individuals, we decided to sample more individuals in each of the study areas in order to increase the chances of sampling a broader range of activity patterns and microenvironment types. We chose to monitor each individual for 1 day in Washington and for 2 days in Denver. This variation in design between the two study areas would allow the EPA to better estimate this design effect for future exposure studies.

(7) When should an individual carry his monitor? Since a person's activity pattern influences his personal exposure, the participants could not be allowed complete freedom of choice in selecting a day to be monitored. However, it was anticipated that a single choice for each individual would result in an extremely poor response rate. Accordingly, several randomly allocated nonoverlapping days were offered to each individual for his/her consideration.

Data Collection Instruments and Procedures

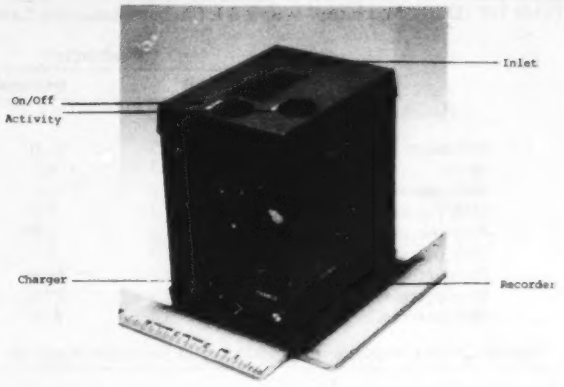
The data collection instruments used in the study included three questionnaires [screening questionnaire, computer model input questionnaire (CMIQ), and participant questionnaire] which provided background data on subjects and their families, a network of fixed-site monitors, the PEMs and activity diaries carried by each subject, and breath samples. These instruments and the procedures employed in using them are described in detail by Hartwell et al. (*4*) and Johnson (*5*).

The screening questionnaire was administered on a household basis primarily by telephone. This questionnaire served as a means of identifying persons eligible for the study. It requested the name of each household member, relationship to the head of household, sex, age, smoking status, occupation, and screening information (typical commute time, use of gas appliances within the home, and presence of attached garage). The completed screening questionnaires yielded a list of eligible individuals from which a stratified sample of potential subjects was selected. The CMIQ was administered by telephone to each sample subject. This questionnaire requested detailed data about the commuting habits of the respondent's household and determined if any member of the household was employed in one of nine occupational categories associated with high CO exposure. This information was sought to augment the activity pattern profiles in SHAPE, a population exposure model developed by Ott (*8*), and NEM, a population exposure model developed by the EPA (*9*). Part B of the CMIQ verified the respondent's address and attempted to set up an appointment for the first visit by an interviewer. The participant questionnaire was administered to each of the persons who actually participated in the study. It included detailed questions about the subject's home environment, work environment, commuting habits, occupation, leisure-time activities, and shopping habits. The participant questionnaire also requested the individual's age, sex, and highest level of education.

A PEM and an activity diary were provided to each subject for a 24-h period. (A new PEM and diary were distributed on the second day in Denver.) The PEM was a modified General Electric (GE) instrument with a DL-1 data logger (*10*) mounted in a compact, tamper-proof casing (Figure 1). The PEM recorded the time and a CO concentration value every time an "activity button" on the top of the instrument was pushed and also automatically every hour on the hour. In both cases, the CO value was the integrated average CO concentration since the last recorded value. Each PEM was capable of operating continuously for 24 h and logging up to 113 CO averages. Quality assurance activities associated with the PEMs included zero-span checks before and after each was placed

Table I. Results of Survey Design for Washington, DC, and Denver, CO

	estimated population	
	Washington 1 220 000	Denver 245 000
first stage		
area segments (census block groups)	250	100
second stage		
household screenings completed	4408	2133
eligibles screened for possible selection	5423	2232
third stage		
eligibles selected to participate	1987	1139
agreed to participate	1161	485
total number of person-days sampled	814	899
number of valid, complete person-days	712	808



(Scale 1:2 approximately)

Figure 1. Personal exposure monitor.

in the field, frequent multipoint calibrations, collection of duplicate collocated samples for evaluating precision, and two independent audits.

Each participant was instructed to fill out a page of the activity diary whenever he/she changed location or activity. Data entered on each diary page included time, activity (e.g., cooking dinner), location (e.g., indoors–residence), address, mode of transit if applicable, and whether smokers were present. For indoor locations, subjects indicated whether a garage was attached to the building and whether a gas stove was in use.

Breath samples were collected at the end of the 24-h period in the subject's home by having each subject blow through a disposable mouthpiece into a 600-mL plastic carboxyhemoglobin bag following the standard method of Jones (*11*). The samples were taken back to the laboratory for analysis that same evening. To measure the CO concentration of the breath sample, a prefilter containing potassium permanganate and activated carbon was inserted between the sample bag and a General Electric CO-3 portable CO monitor. The analysis relating breath CO concentrations to the measured CO exposures obtained during this study has been reported by Wallace (*12*).

Study Results

By use of the Household Screening Questionnaire data collected from 4408 households in Washington, DC, and 2133 households in the Denver metropolitan areas (Table I) weighted estimates were computed of population characteristics. The fraction of selected nonsmoking adult individuals who agreed to participate was 58% in Washington and 43% in Denver. Although these response rates appear low, they are consistent with response rates of similar studies that required personal monitoring, such as TEAM (13) and Harvard (*14*). Low response rates affect population estimates if the nonresponders are different in their exposures from responders. Unlike attitudinal surveys, surveys which measure objective parameters such as exposure to CO, are less likely to be affected by nonresponse. Thus, the results are expected to be representative of the target population in each city.

Since probability-sampling methods were used to select the subjects to be monitored, sampling weights based upon selection probabilities and adjustments to compensate for potential bias due to nonresponse were used in all analyses. The initial sampling weights were simply the reciprocals of the probabilities of selection. Standard weighting class nonresponse adjustment procedures (*15*) were used to adjust the initial weights for household-level nonresponse to the household screening survey and person-level nonresponse to the exposure monitoring. These weight adjustment procedures reduce the potential bias due to nonresponse to the extent that respondents and nonrespondents are more alike within weighting classes than between weighting classes. Details of the weight adjustment procedures are provided in Whitmore et al. (*3*).

The adjusted sampling weights were used to produce all population estimates of selected characteristics for the households and individuals in the two urban areas as shown in Table II. For example, more than twice as many homes have gas stoves in Washington than in Denver (64% vs. 25%). On an individual basis, there is a higher percentage of smokers in Denver than in Washington (38% vs. 33%). Additional population characteristics are provided by Hartwell et al. (*4*) and Johnson (*5*).

Table II. Population Household and Individual Characteristics for Washington and Denver[a]

	location			
	Washington estimated		Denver estimated	
type	total	percentage	total	percentage
household				
use fireplace	316 925 (29 538)[a]	33.2 (3.0)	103 211 (16 030)	29.9 (3.6)
use wood stove	37 721 (6 858)	4.0 (0.8)	20 314 (2 841)	5.9 (0.9)
use gas furnace	532 347 (40 943)	55.8 (3.6)	245 902 (2 231)	71.2 (3.8)
use gas stove	609 029 (49 353)	63.8 (3.3)	85 542 (7 308)	24.8 (2.4)
use gas water heater	542 855 (37 564)	56.9 (3.1)	269 810 (20 930)	78.2 (3.3)
attached garage	165 919 (22 525)	17.4 (1.9)	108 934 (11 188)	31.6 (2.8)
individual				
male	1 286 056 (133 431)	48.2 (0.9)	415 730 (30 762)	47.4 (0.9)
smokers (13 years or older)	639 739 (69 002)	33.2 (1.8)	244 884 (29 266)	38.0 (2.3)
work (13 years or older)	1 333 061 (96 555)	70.2 (1.4)	464 960 (38 133)	72.1 (1.6)
travel ≥ 3 times/week	1 606 757 (110 928)	84.1 (0.8)	530 420 (41 049)	82.2 (1.3)

[a] Values in parentheses represent standard errors.

Table III. Daily Maximum 1- and 8-h Carbon Monoxide Levels by City (ppm)

	Washington				Denver			
	ambient[a]		personal exposure		ambient[b]		personal exposure	
statistic	1 h	8 h	1 h	8 h	1 h	8 h	1 h	8 h
minimum	0.8	0.7	<1.0	<1.0	0.7	0.6	<1.0	<1.0
mean	3.2	2.3	6.7	2.8	6.6	4.2	10.0	4.9
10th percentile	1.4	1.1	1.4	<1.0	2.8	1.7	2.2	1.1
25th percentile	1.9	1.4	2.3	1.3	4.5	2.9	4.1	2.0
50th percentile	2.8	1.9	4.2	2.2	6.0	3.7	8.0	3.5
75th percentile	4.1	2.7	7.4	3.8	8.2	5.3	12.7	6.9
90th percentile	5.9	4.1	12.5	6.0	10.6	7.0	18.5	9.4
95th percentile	6.9	4.8	17.0	8.0	13.0	8.7	26.3	12.1
98th percentile	7.9	5.4	25.0	12.0	14.7	9.2	39.0	16.2

[a] Based on the composite distribution of 11 fixed-site monitors. [b] Based on the composite distribution of 15 fixed-site monitors.

Table IV. Summary of CO Exposure Levels and Time Spent per Day in Selected Microenvironments

	location							
	Denver				Washington, DC			
	concentration,[a] ppm			median	concentration,[a] ppm			median
microenvironment	n	$\bar{x}$	SE	time, min	n	$\bar{x}$	SE	time, min
indoors, parking garage	31	18.8	4.96	14	59	10.4	4.43	11
in transit, car	643	8.0	0.32	71	592	5.0	0.14	79
in transit, other (bus, truck, etc.)	107	7.9	0.61	66	130	3.6	0.30	49
outdoors, near roadway	188	3.8	0.36	33	164	2.6	0.20	20
in transit, walking	171	4.2	0.45	28	226	2.4	0.29	32
indoors, restaurant	205	4.2	0.29	58	170	2.1	0.32	45
indoors, office	283	3.0	0.20	478	349	1.9	0.27	428
indoors, store/shopping mall	243	3.0	0.22	50	225	2.5	0.49	36
indoors, residence	776	1.7	0.10	975	705	1.2	0.10	1048
indoor, total	776	2.1	0.09	1343	705	1.4	0.08	1332

[a] n = number of person-days with nonzero durations. $\bar{x}$ = mean. SE = standard error.

Personal Exposure

The population of inference, adult nonsmokers was estimated to include about 1 220 000 and 245 000 individuals in Washington and Denver, respectively. Unless specifically noted otherwise, all results shown in this section apply to this population or to some specified subgroup of this population. Note also that the results apply only to the period of data collection—from the date field monitoring began until the date field monitoring ended.

The present EPA standards for ambient levels of carbon monoxide are expressed in terms of 1- and 8-h averages. For ease in comparison with these standards, the daily maximum 1- and 8-h exposures were calculated for the target population. Weighting factors accounted for the probability of selecting a particular subject and for nonresponse caused by refusals, instrument problems, and unacceptable activity diary data. Table III summarizes these results together with the composite fixed-site (ambient) distributions that were formed by pooling all the fixed-site data from the study area collected during the study. It can be seen that the upper half of the distributions of 1- and 8-h personal exposure are higher than the corresponding portion of the distributions of ambient concentrations. In addition, the Denver ambient levels were approximately double those observed in Washington, DC.

Diurnal patterns were developed to compare the exposure data with fixed-site values. For example, the weekday diurnal CO patterns for Denver, shown by the dashed line in Figure 2, was constructed by compositing the fixed site data from the 15 urban sites. The composite exposure pattern, shown by the solid line, is a composite of all 899 person-days sampled. The plot illustrates that average CO concentrations observed at fixed stations during the traffic

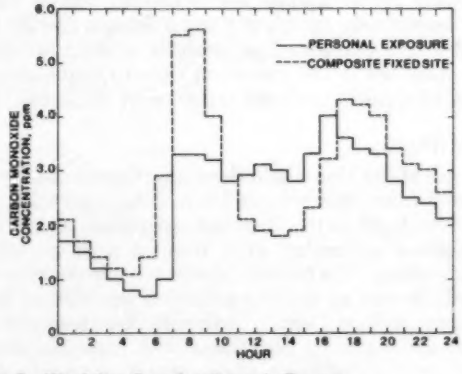


Figure 2. Weekday diurnal patterns in Denver.

rush periods are higher than the concurrently measured personal exposures. In Denver the midday personal exposures exceed the fixed site levels, a likely consequence of indoor sources.

By use of information from the activity diary, microenvironments with high concentrations could be identified (Table IV). Those microenvironments associated with commuting had the highest CO levels in both study areas. By contrast, the lowest levels were measured in the indoor microenvironments, probably due partly to time of day and duration of exposure. On the average, study participants spent over 22 h/day indoors.

An analysis was conducted of Denver residential indoor exposures to determine the contribution of three potential CO sources. Average PEM indoor mean exposure (unadjusted for cofactors) was increased 2.59 ppm (134%) by gas stove operation, 1.59 ppm (84%) by smokers other than

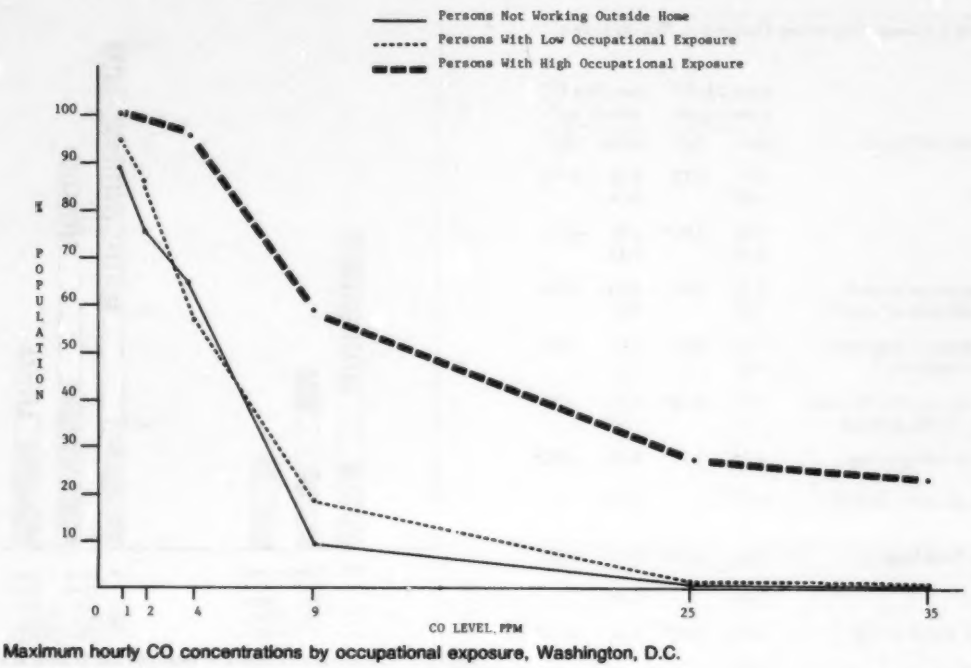


Figure 3. Maximum hourly CO concentrations by occupational exposure, Washington, D.C.

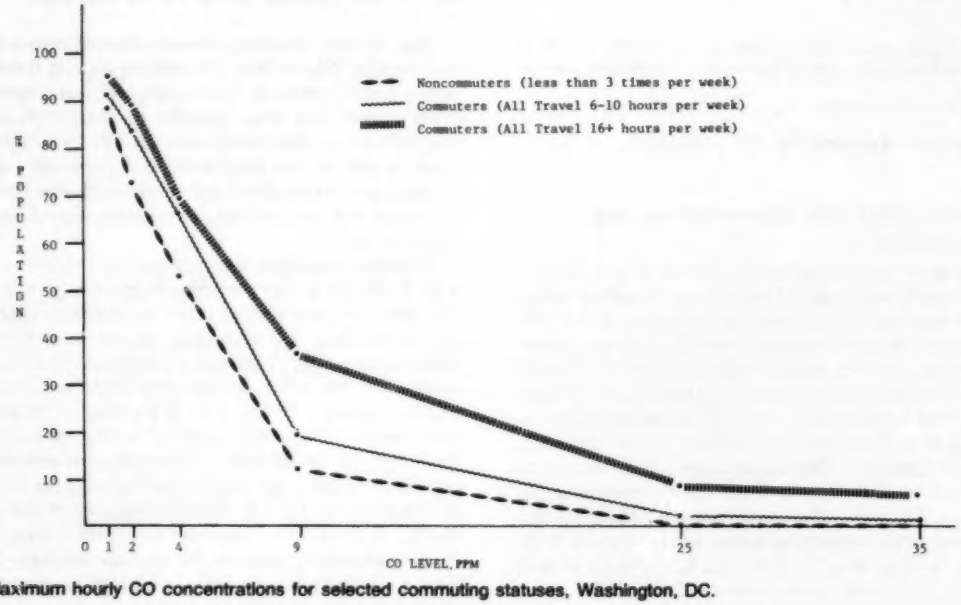


Figure 4. Maximum hourly CO concentrations for selected commuting statuses, Washington, DC.

study participants, and 0.41 ppm (22%) by attached garages. [Arithmetic averages are used throughout this paper for two reasons: the statistical tests are based upon the distribution of sample averages which converges to normality as the sample size increases and the arithmetic mean is more appropriate for characterizing exposure (*16*).] As noted previously, only nonsmokers were invited to participate in the study. Certain occupational exposures emerged such as those involving the use of gasoline engines or gas appliances. Also, exposures on days with high ambient CO concentrations (greater than 9 ppm 8-h average) were significantly higher by 2.4 ppm (75% increase) than on days with low CO concentrations (*17*).

Table V shows a statistical analysis of pairwise comparisons of Washington exposure subgroups (*18*). In contrast with Denver, the results indicate no significant differences between low and high CO days or between the various categories of stove type. However, significant differences are evident for several other groups: persons not working outside the home vs. those that do; persons with low occupational exposure vs. those with high occupational exposure; commuters vs. noncommuters; commuters with less than 6 h of total travel per week vs. commuters with 6 or more hours per week. [Twenty-nine individuals were categorized as belonging to occupations with potential for increased CO exposure. The occupations include truck drivers, taxi drivers, bus drivers, automobile mechanics, garage workers, and policemen.) Weekdays vs. weekend days are significantly different only for the 1-h maximum. The asterisks (Table V) indicate statistical significance at the 0.05 level. Figures 3 and 4 show the influence of occupation and commuting, respectively, on

Table V. Tests between Exposure Groups in Washington, DC[a]

population subgroup	max 1-h CO concn, ppm mean	max 1-h CO concn, ppm diff	max 8-h CO concn, ppm mean	max 8-h CO concn, ppm diff
low CO days	6.71	0.11	2.72	0.31
high CO days[b]	6.82		3.03	
weekdays	7.35	−2.05*	2.94	−0.51
weekend days	5.30		2.43	
gas stove at residence–vented	6.40	0.65	2.99	0.04
gas stove at residence–unvented	7.05		3.03	
gas stove at residence–unvented	7.05	0.23	3.03	0.48
no gas stove at residence	6.82		2.55	
persons not working outside home	5.22	2.16*	2.35	0.63*
persons working outside home	7.38		2.98	
persons with low occupational exposure	6.34	15.77*	2.66	4.85*
persons with high occupational exposure	22.11		7.51	
noncommuters (less than 3 times/week)	4.94	2.12*	2.30	0.58*
commuters	7.06		2.88	
commuters—all travel = 0–5 h/week	5.04	2.86*	2.35	0.74*
commuters—all travel = +6 h/week	7.90		3.09	

*Asterisk indicates difference between two means significant at 0.05 level. [b]Any fixed-site monitor had at least 1 h greater than 10 ppm.

maximum hourly exposure for the population in Washington.

Comparisons of Fixed-Site Concentrations and Personal Exposures

During the study period ambient CO data were collected as part of the state and local air monitoring program using reference, or equivalent, nondispersive infrared (NDIR) instrumentation. Eleven existing fixed-site monitors were operating within the Washington Study Area; 15 sites (6 existing and 9 temporary) were operating in the Denver Study Area. The highest daily 1-h maximum varied across the sites from 8 to 22.4 ppm in Washington and from 9.6 to 44.1 ppm in Denver. The highest daily 8-h maximum varied from 5.6 to 12.5 ppm in Washington and from 5.8 to 20.7 ppm in Denver. The corresponding medians for both cities and both averaging times were 2.8 ppm (1 h) and 1.9 ppm (8 h) in Washington and 6.0 ppm (1 h) and 3.7 ppm (8 h) in Denver (refer also to Table III).

Figure 5 shows a bar chart of the distributions of maximum 1-h CO values obtained from the personal exposure monitors and the fixed-site monitors in Washington and Denver, respectively. The bar on the left represents the maximum 1-h distribution of personal exposures. The statistics chosen for illustration include the mean, 90th percentile, and 98th percentile. The other two bars are distributions of ambient data reported by the fixed site measuring the highest CO concentrations and composite distribution representing the average of all fixed sites. It can be seen that fixed-site data provide an unreliable representation of exposure. The greatest difference occurs when the highest 10% of the distribution of personal exposure is compared with the highest 10% of fixed-site data. This discrepancy can be explained by the contribution of a combination of in transit, indoor, and occupational sources to personal exposure. It can also be seen (Figure 6) that the 8-h frequency distribution of personal exposure is generally higher than the corresponding fixed-site composite distributions in both cities. This difference may be quite significant with respect to interpreting exposure according to some standard level. For example, approximately 4% of the maximum 8-h personal exposures in Washington exceeded 9 ppm, although the fixed-site distribution did not indicate exposures were likely to occur above 9 ppm.

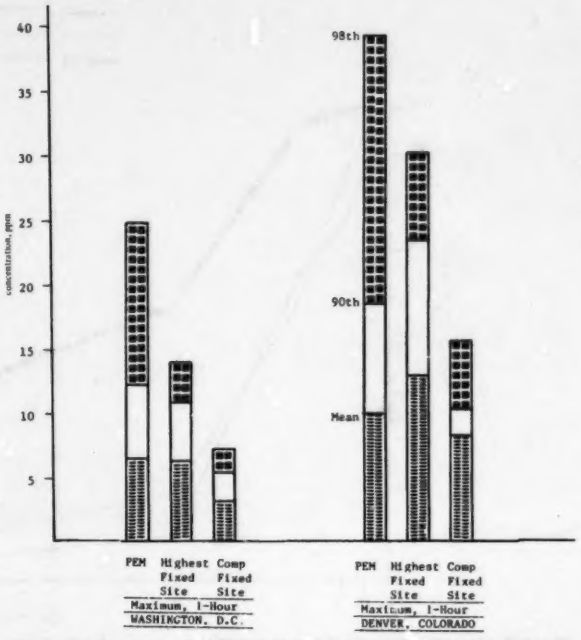


Figure 5. Comparison of PEM and fixed-site distributions in Washington, DC, (11 fixed sites) and Denver, CO (15 fixed sites).

Statistical analyses that attempt to relate the PEM data with fixed-site measurements are generally unenlightening. For example, correlation analyses indicate that PEM and fixed-site data are generally poorly correlated (e.g., in Washington, the correlations between the nearest fixed station and the office or residence PEM levels are only 0.24 and 0.14, respectively, and in Denver, 0.23 and 0.27, respectively). Thus, the ambient levels are explaining less than 10% of the variance of the personal exposures. Such results are consistent with other findings for CO and other pollutants (*13*, *14*, *19*). The sensitivity of the correlation results to fixed-site location was examined by a weighted linear regression analysis for various microenvironments. Again the correlations were quite low, ranging from a low of 0.1 to a high of 0.22. Overall, these analyses suggest that 1-h values reported by the nearest fixed-site monitor or group of fixed-site monitors do not provide a good means of predicting simultaneous PEM values.

Denver PEM data were categorized according to high days (days with the maximum 8-h ambient level greater than or equal to 9 ppm) and low ambient days (less than 9 ppm) and statistically compared; the distribution of personal exposures between these two groups were found to be significantly different ($p < 0.001$). This result suggests that personal exposures are related to ambient levels, although the functional form is not clear.

Quality Assurance

During the study, two external system and performance audits were conducted by the EPA. The first audit was conducted in November at the start of the study, and the

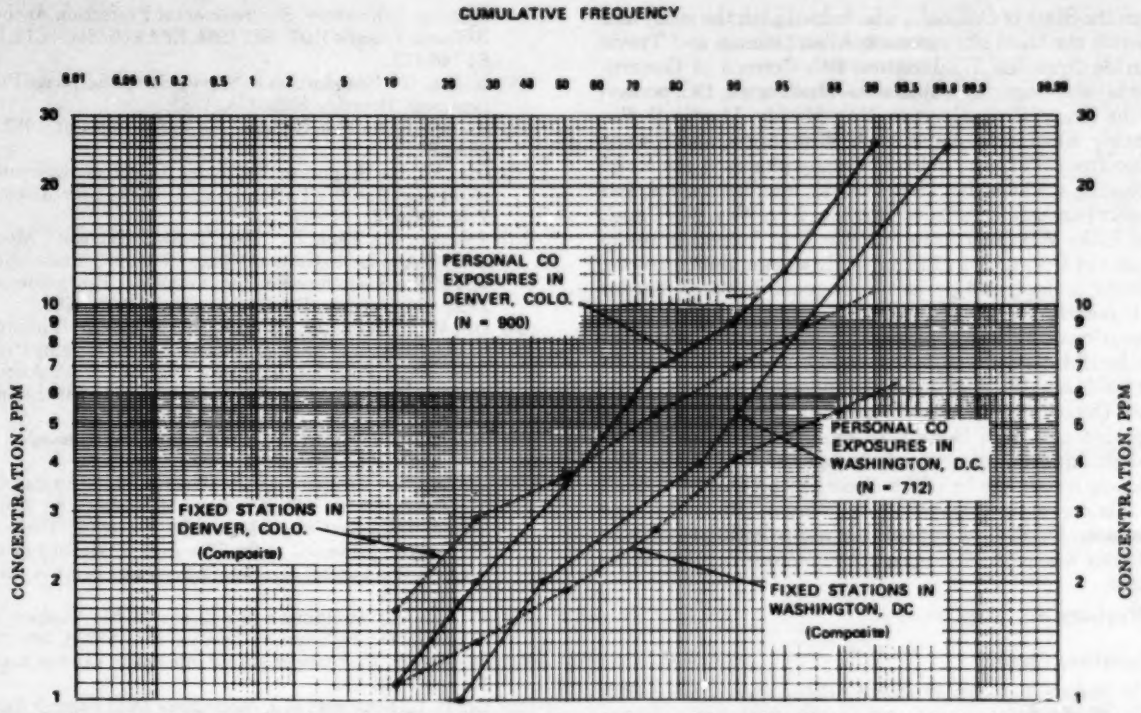

CUMULATIVE FREQUENCY
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
CONCENTRATION, PPM
PERSONAL CO EXPOSURES IN DENVER, COLO. (N = 900)
PERSONAL CO EXPOSURES IN WASHINGTON, D.C. (N = 712)
FIXED STATIONS IN DENVER, COLO. (Composite)
FIXED STATIONS IN WASHINGTON, DC (Composite)

Figure 6. Frequency distribution of maximum 8-h CO population exposures in Denver, CO, and Washington, DC, plotted on logarithmic-probability paper, along with 8-h maximum concentration observed at fixed stations, Nov 1982–Feb 1983.

final audit occurred in February. At both locations during both audits, the PEM and breath measurements were within ±10% of the audit results, and the fixed monitor results were within ±5% of the audit results.

Across the entire project, postsample monitor performance was within ±10% of the slope of the calibration curves and within ±1.5 ppm of the intercept nearly 90% of the time. An analysis of variance of duplicate hourly PEM measurements under field conditions indicated that about 5–6% of the total variation among the hourly duplicate readings was due to deviation in PEM measurements. PEMs attached to a common manifold supplying ambient air to a fixed-site monitor yielded paired values with a mean difference of 8.3% (fixed site being higher) and a standard deviation of 22%. On the basis of this information an estimate of the PEM bias is about 0.5 ppm lower than the corresponding ambient result. The primary reason for this bias is thought to be a result of voltage drop from the PEM battery causing a drop in flow rate. PEM failure accounted for an average loss of about 15% of all subject days.

Quality assurance procedures were also applied to the information collection activities. Ten percent of the telephone interviews were monitored at random by supervisors to ensure correct data input to questions asked by the interviewer. All questionnaire information was coded into the computer, validated, and matched with corresponding exposure measurements. When applied to the Denver data, for example, these procedures indicated approximately 87% of the subject days were within acceptable limits with respect to both the PEM and activity diary entries. A complete description of the quality assurance procedures for the entire study can be found in ref 4 and 5.

Conclusions

EPA's exposure monitoring research program has developed and successfully field tested a new methodology to better estimate population exposures to air pollutants. This methodology combines statistical survey design techniques with miniaturized automated PEMs to produce exposure profiles for a representative population sample. These studies have provided a rich data base that should prove invaluable in answering questions concerning the factors that affect exposure, the ability of fixed-site data to represent personal exposures, and the validity of proposed exposure models. The data collected during this study support earlier findings that CO exposure associated with commuting are higher than for noncommuters, gas stove operation increases CO levels in residences, and certain occupational groups have higher exposures. Furthermore, personal exposure levels over an urban area are higher on days in which the ambient levels exceed the 8-h standard level of 9 ppm. In both cities the percent of maximum daily 8-h personal exposures exceeding the standard level of 9 ppm was considerably greater than the percent of fixed-site 8-h measurement exceeding the standard level. The results indicate that the effects of personal activity and indoor sources of CO greatly influence one's personal exposure. Models for estimating population exposures to CO which omit these effects are likely to yield inaccurate results. More accurate urban scale exposure estimates can be obtained through proper application of a methodology that combines survey sampling techniques and personal exposure monitors.

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